Polarization transfer in elastic Rayleigh scattering *

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Studies on the elastic Rayleigh scattering of photons by bound atomic (or ionic) electrons have a long tradition. Since the mid 1930's, a large number of experimental and theoretical works have dealt with the total as well angle–differential Rayleigh cross sections [1]. More recent investigations were focused, moreover, on the linear polarization of the scattered photons. Of particular interest here is the question of how this polarization is affected if the incident light is itself (linearly) polarized. Owing to recent advances in coherent light sources and efficient detection techniques, a new generation of experiments has currently become feasible, in which such a "polarization transfer" can be explored for heavy atomic targets and the radiation in the x–ray region. Polarization analysis of the Rayleigh scattering in the high–Z—and—high–energy domain may serve as a valuable tool for exploring this second–order quantum electrodynamical (QED) process in very strong electromagnetic fields.

In order to analyze the current and future experiments on the polarization transfer in elastic Rayleigh scattering of x–rays by heavy targets, detailed theoretical study has been performed by us based on the second–order perturbation theory and Dirac relativistic equation [2]. The practical application of such a perturbative approach requires the knowledge about the *complete* Dirac spectrum of an atom (or ion), including not only bound– but also positive and negative energy continuum–states. In our study, this spectrum was represented by means of the Coulomb Green's function:

$$G_E(\boldsymbol{r}, \boldsymbol{r}') = \sum\!\!\!\!\!\!\!\int_\nu \frac{\psi_\nu^\dagger(\boldsymbol{r})\,\psi_\nu(\boldsymbol{r}')}{E_\nu - E}\,, \tag{1}$$

constructed from the eigensolutions $\psi_\nu(\boldsymbol{r}) \equiv \psi_{n_\nu j_\nu, \mu_\nu}(\boldsymbol{r})$ of the Dirac Hamiltonian. By using the analytical representation of $G_E(\boldsymbol{r}, \boldsymbol{r}')$ in terms of the regular and irregular Whittaker functions [3] we were able to perform an accurate perturbative calculations of the angular as well as polarization properties of scattered Rayleigh photons.

With the help of the relativistic Green's function approach we investigated, in particular, the elastic scattering of completely linearly polarized x–rays on hydrogen–like ions in their ground state. For example, Fig. 1 displays the angular distribution (left panel) and the degree of linear polarization (right panel) of scattered photons for the case of xenon Xe^{53+} target and three different energies $\hbar\omega$ of the incident light. As seen from the figure, both (angular and polarization) properties appear to be very sensitive to the photon energy. In particular, if $\hbar\omega \cong 45$ keV, which is just 10 % above the $1s$ ionization threshold, the Rayleigh photons are strongly polarized over the entire angular range, except for $\theta \approx 80$–$100°$, and their emission pattern is almost dipole–like, $W(\theta) \sim \cos^2\theta$. In contrast, the increase of the energy leads to (i) a strongly enhanced forward emission and to (ii) a significant *reduction* of the polarization of outgoing radiation. This reduction is largest for the backward scattering but may also reach 20–30 % for the emission angles in the range $30° \lesssim \theta \lesssim 60°$, where the photon yield is high. Based on our theoretical analysis, we argue that such a "depolarization" of light in the course of elastic scattering is caused mainly by the higher, non–dipole components of the electromagnetic field. The measurements of the depolarization effects, which is feasible today with the help of available solid–state detectors, can reveal, therefore, useful information about the details of photon–matter interactions in the extreme relativistic regime; the topic which attracts currently much attention both in intense–laser and heavy–ion physics.

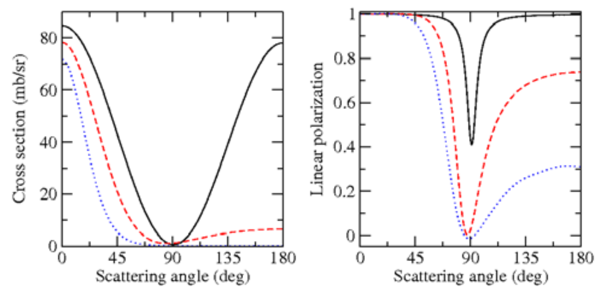

Figure 1: The angle–differential cross section (left panel) and the degree of linear polarization (right panel) of elastically scattered x–rays on hydrogen–like xenon Xe^{53+} ions in their ground state. Relativistic calculations were performed for the completely linearly polarized incident light with energies $\hbar\omega$ = 1.1 I_{1s} (solid line), 5 I_{1s} (dashed line) and 10 I_{1s}, where $I_{1s} \cong 41$ keV refers to the $1s$ ionization threshold. Data from Ref. [2].

References

[1] R. Pratt, Rad. Phys. Chem. **74**, 411 (2005).
[2] A. Surzhykov *et al.*, Phys. Rev. A **88**, 062515 (2013).
[3] P. Koval and S. Fritzsche, Comp. Phys. Commun. **152**, 191 (2003).

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